

Toward a Tandem Cell with all II-VI Semiconductors by Magnetron Sputtering

A.D. Compaan, Shanli Wang, Akhlesh Gupta, and R.W. Collins

The University of Toledo

Supported by: NREL High Performance PV Program

OUTLINE

- Overview of UT's High Performance PV project
- II-VI alloys for top and bottom cells
- Real-time spectroscopic ellipsometry for growth and nucleation studies
- Materials for interconnect junctions and transparent contacts
- A prototype two-terminal tandem (CdTe/HgCdTe)

Sputtered II-VI Alloys and Structures for Tandem PV

Overview of UT High Performance PV project--

- Task 1 Sputtered top cell II-VI alloys including real time spectroscopic ellipsometry**
- Task 2 Transparent contacts/window layers and recombination junctions**
- Task 3 Interconnect studies and related nonideal tandem cell modeling**
- Task 4 HgCdTe bottom cell studies/back contact**
- Task 5 Characterization and stress studies**

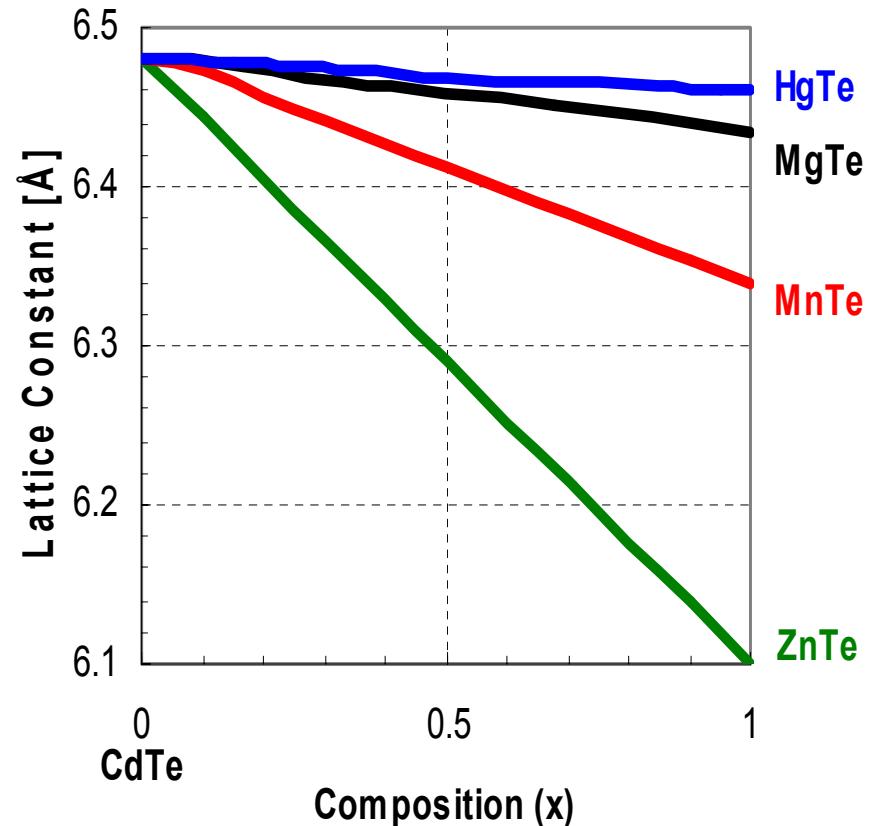
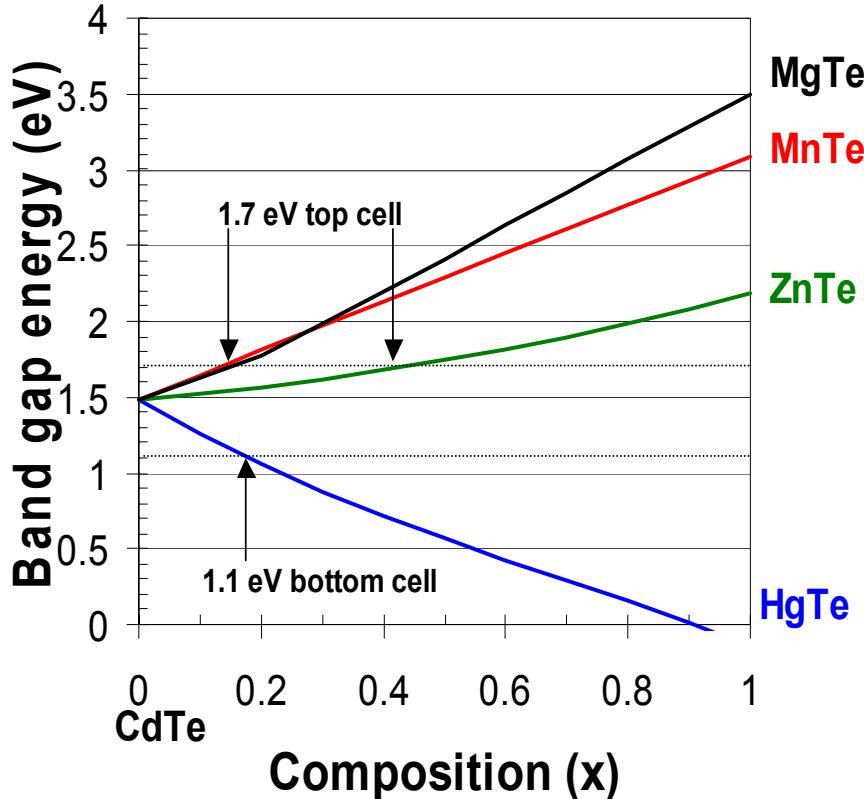
Sputtered II-VI Alloys and Structures for Tandem PV

Overview of UT project--

- **Task 1 Sputtered top cell II-VI alloys including real time spectroscopic ellipsometry**
- **Task 2 Transparent contacts/window layers and recombination junctions**
- Task 3 Interconnect studies and related nonideal tandem cell modeling**
- **Task 4 HgCdTe bottom cell studies/back contact**
- Task 5 Characterization and stress studies**

II-VI alloy candidates for tandem structures

band gap and lattice constant vs. composition for four II-VI alloy systems



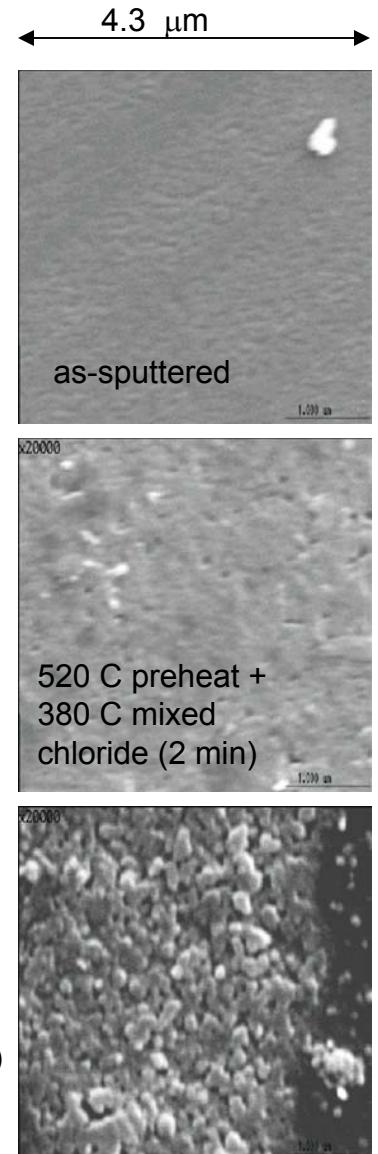
Some results on ternary II-VI alloys

Best single junction superstrate cell performance of different p-type sputtered alloy films with n-CdS

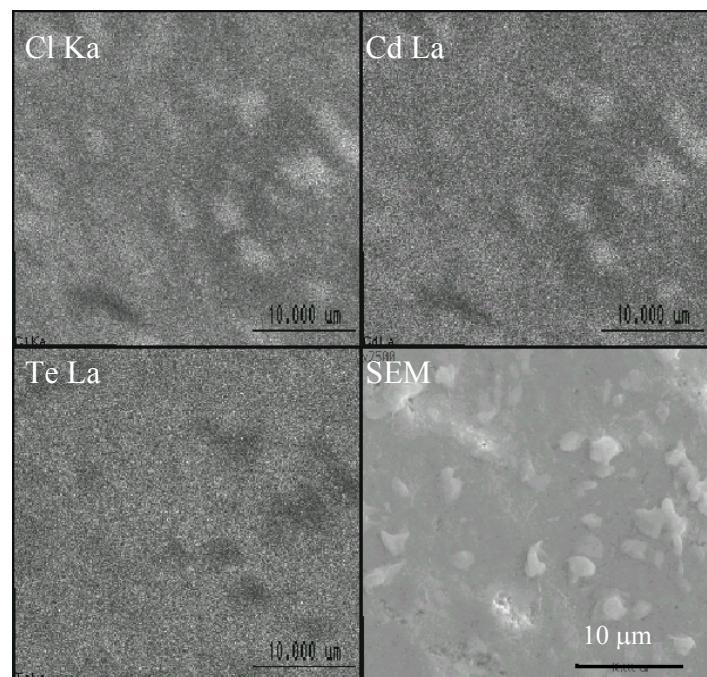
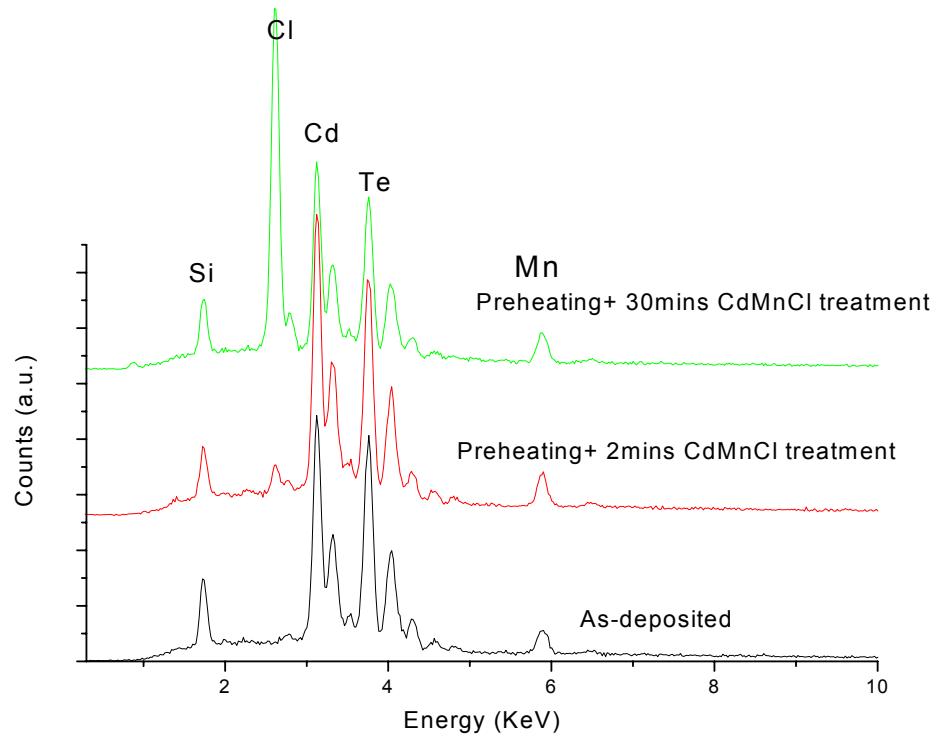
Alloys	Voc (V)	Jsc (mA/cm ²)	FF (%)	Eff (%)
HgCdTe	0.45	20.0	59	5.3
CdMnTe	0.58	5.6	31	1.0
CdZnTe	0.74	19.0	71	7.2

- wide gap alloys are difficult to activate with chloride processing
- HgCdTe looks promising
- CdMgTe not yet examined

SEM images of CdMnTe with different postdeposition treatment conditions



X-ray maps of CdMnTe films after Cl activation



Toward a Tandem Cell with all II-VI Semiconductors by Magnetron Sputtering

A.D. Compaan, Shanli Wang, Akhlesh Gupta, and R.W. Collins

The University of Toledo

OUTLINE

- Overview of UT's High Performance PV project
- II-VI alloys for top and bottom cells
- Real-time spectroscopic ellipsometry for growth and nucleation studies
- Materials for interconnect junctions and transparent contacts
- A prototype two-terminal tandem (CdTe/HgCdTe)

Sputtered II-VI Alloys and Structures for Tandem PV

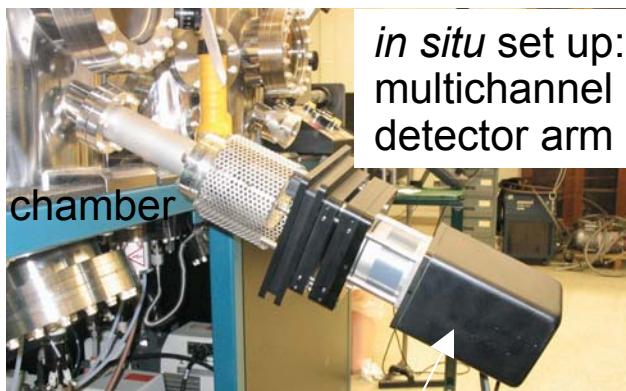
Progress on Task 1: implementation of *in situ*, on-line spectroscopic ellipsometry (SE);
Progress on Task 5: *ex situ* SE characterization of substrate and II-VI alloy materials

Progress in Phase I

- A versatile instrument for ex situ and real time SE has been installed at University of Toledo
- CdTe depositions on opaque substrates (Mo & c-Si have been analyzed by real time SE to extract deposition rate and optical properties
- In situ substrate temperature calibration and monitoring method is in progress
- Ex situ studies of completed CdTe solar cells have been undertaken and analysis is underway.



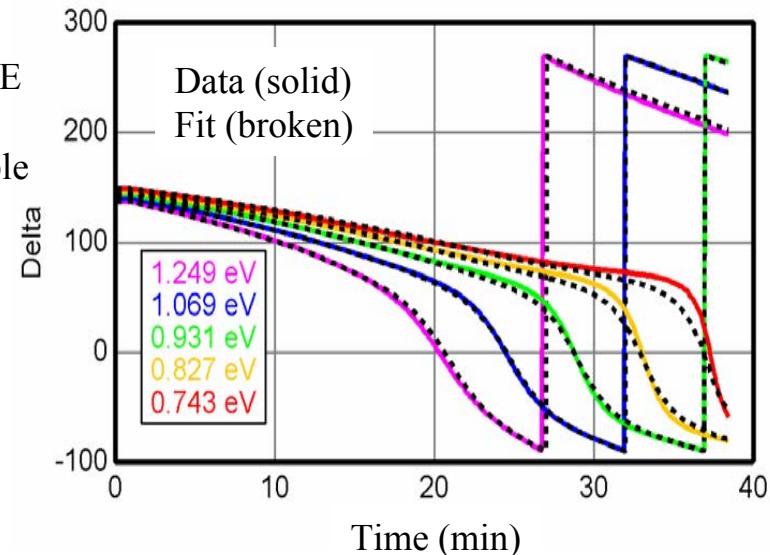
ex situ
optical
set up



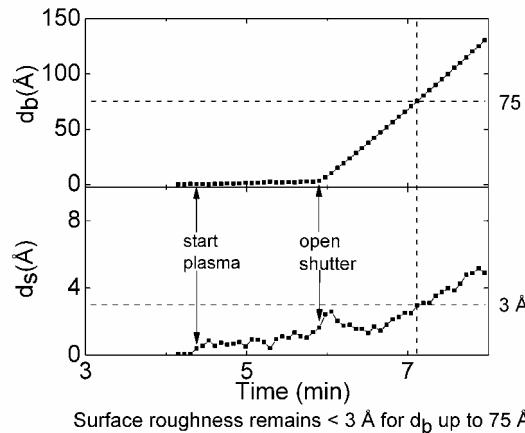
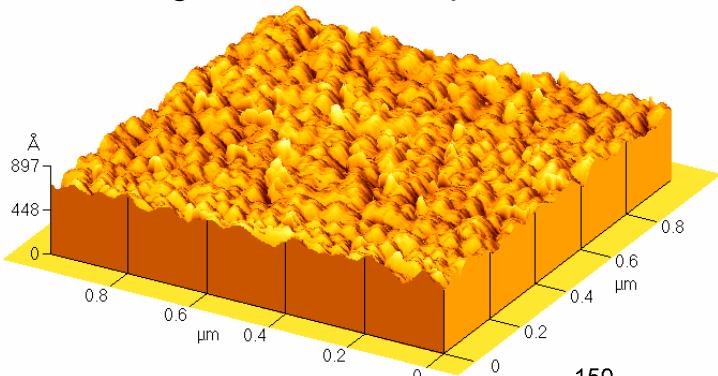
in situ set up:
multichannel
detector arm

Dual sources:
QTH: (0.75 – 3 eV)
D₂: (3 eV – 6.5 eV)

Dual detectors:
InGaAs PDA: (0.75 – 1.2 eV)
Si CCD: (1.2 – 6.5 eV)

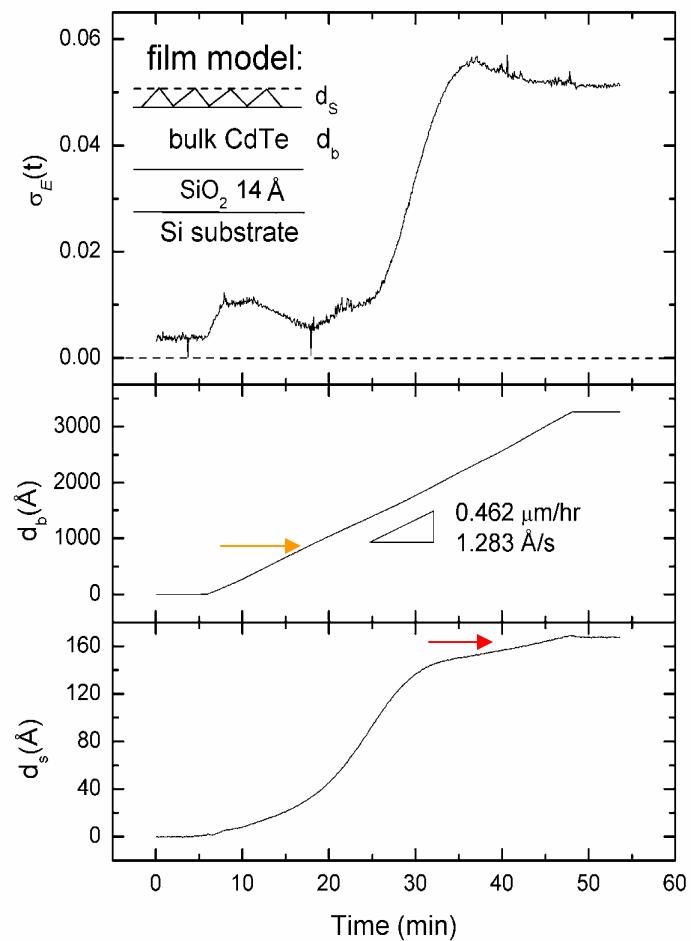
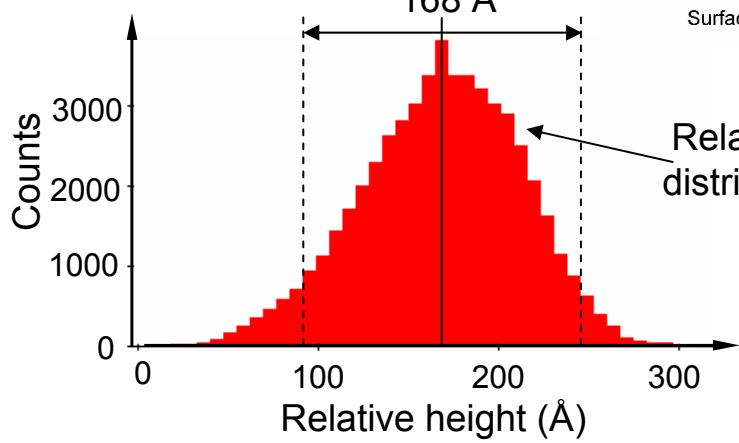


AFM image after CdTe deposition on c-Si



Final d_s from RTSE
168 \AA

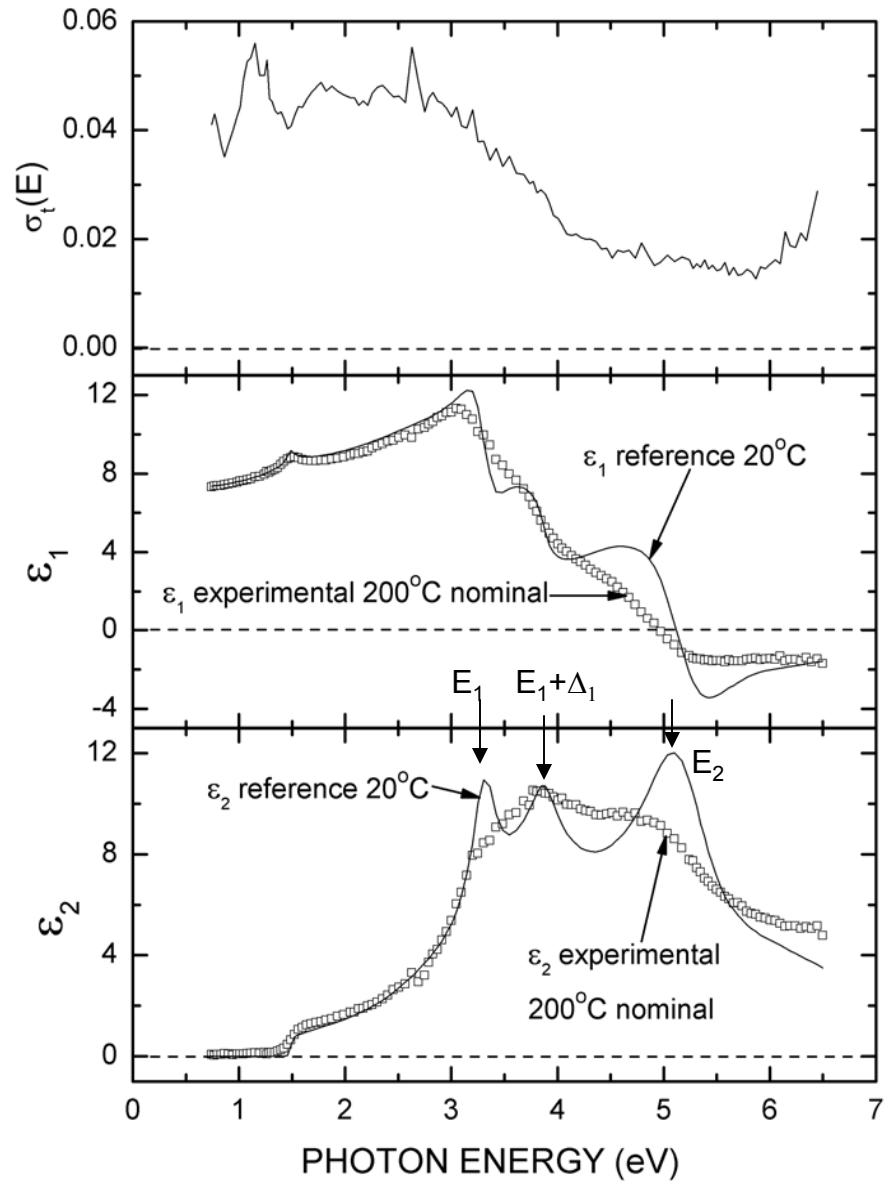
Relative height distribution from AFM



Instrument development:

J. Lee, P. I. Rovira, I. An, and R. W. Collins, *Review of Scientific Instruments* **69**, 1800 (1998).

How do the optical constants of a 900 Å film of CdTe on Si compare with bulk single crystal CdTe?



Toward a Tandem Cell with all II-VI Semiconductors by Magnetron Sputtering

A.D. Compaan, Shanli Wang, Akhlesh Gupta, and R.W. Collins

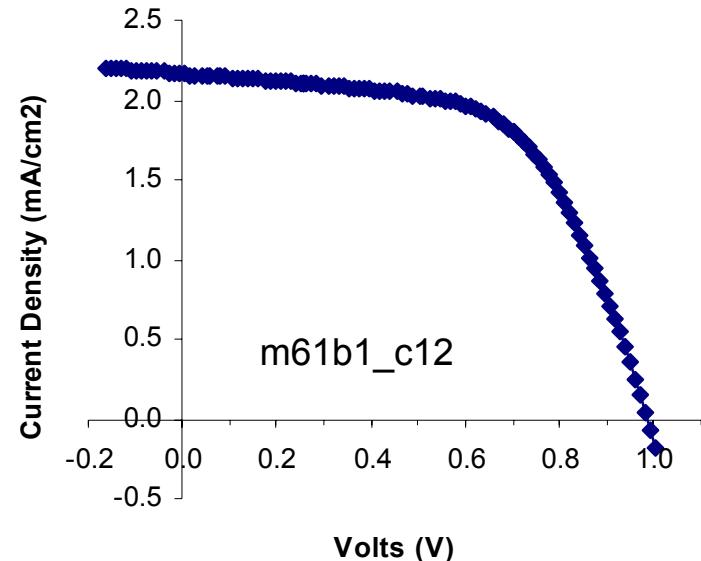
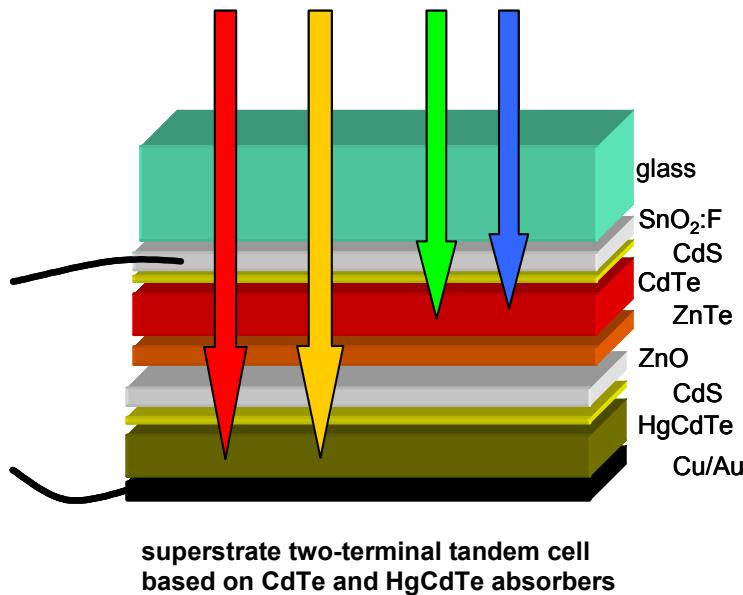
The University of Toledo

OUTLINE

- Overview of UT's High Performance PV project
- II-VI alloys for top and bottom cells
- Real-time spectroscopic ellipsometry for growth and nucleation studies
- Materials for interconnect junctions and transparent contacts
- A prototype two-terminal tandem (CdTe/HgCdTe)

sputtered polycrystalline II-VI tandem cell

- Tec-7 glass/*sputtered layers*/evap Cu/Au
- CdTe (1.5 eV) and HgCdTe (1.0 eV) absorbers
- current is limited by HgCdTe due to CdTe top cell
- ZnTe:N/ZnO:Al interconnect junction works!



$$V_{OC} = 0.9916 \text{ V}$$

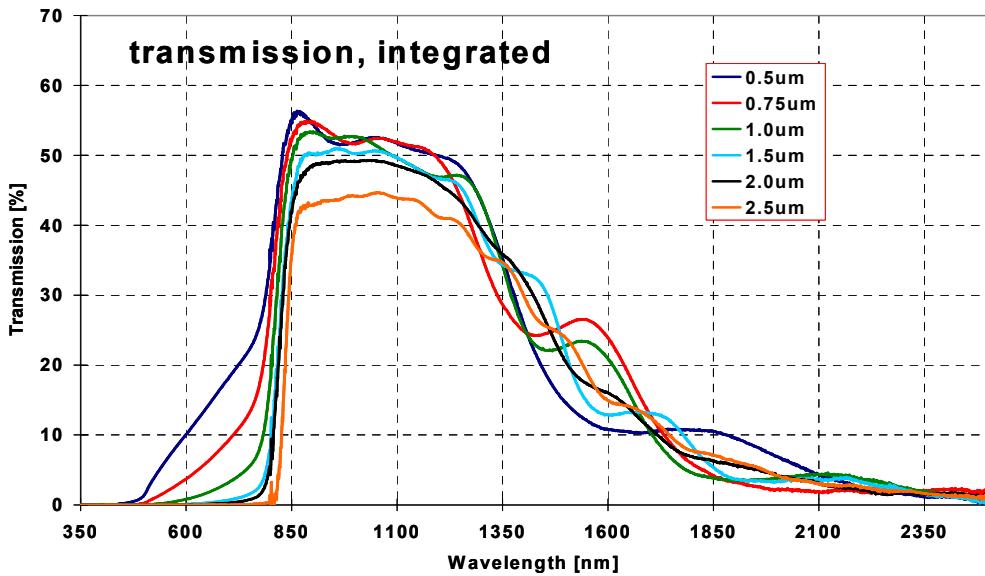
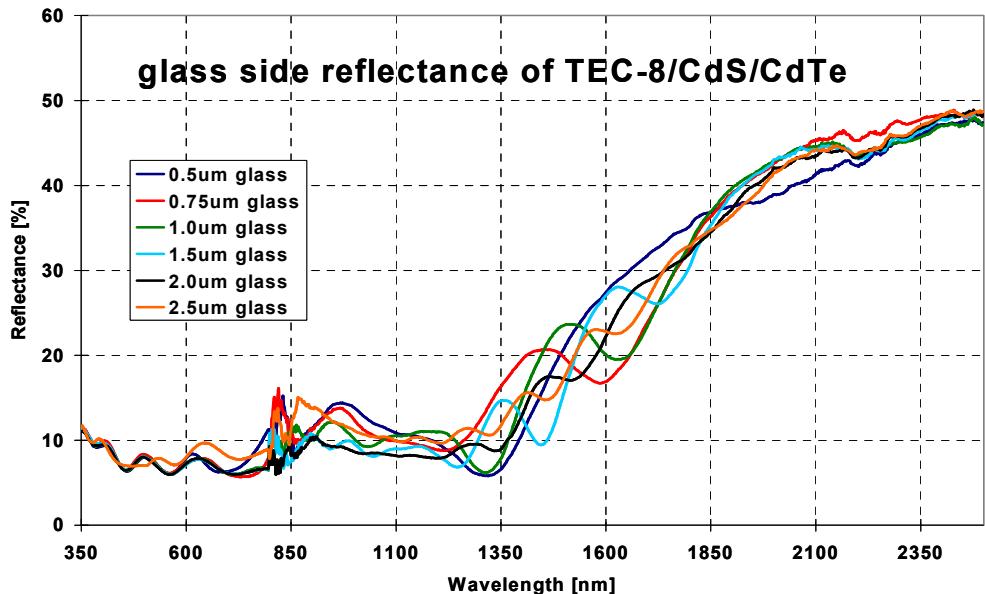
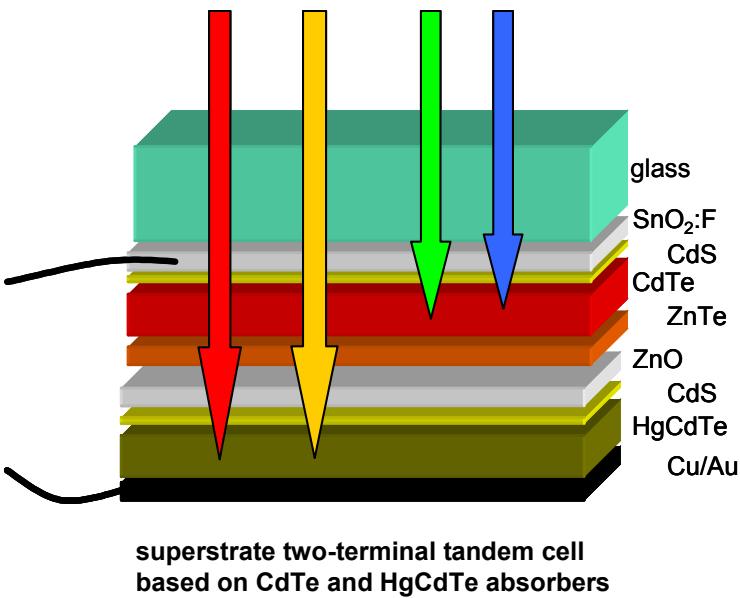
$$J_{SC} = 2.164 \text{ A/cm}^2$$

$$FF = 58.78\%$$

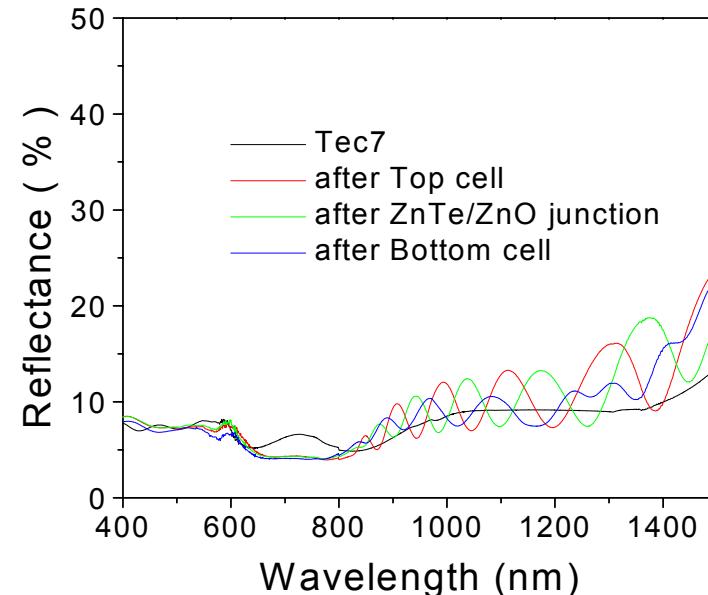
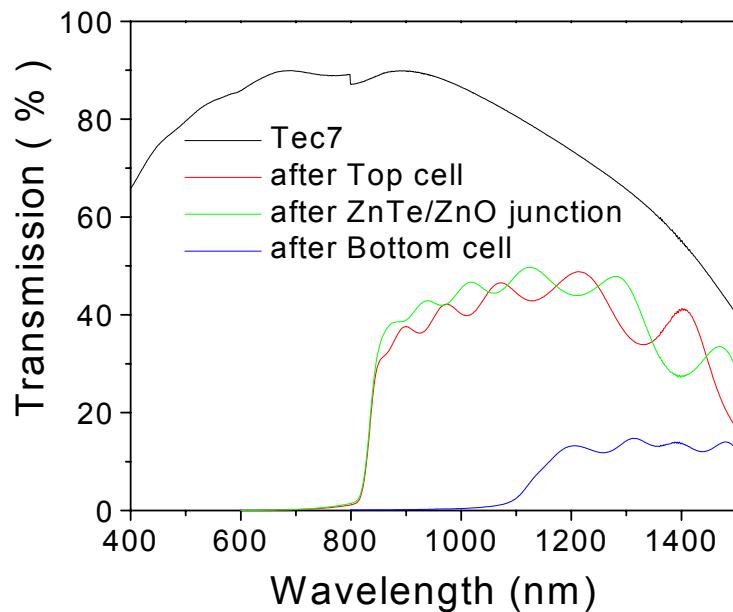
NREL X25 IV system, T=25 °C

2/23/04

reflectivity and transmission through TEC-8/CdS/CdTe structures for several CdTe thicknesses

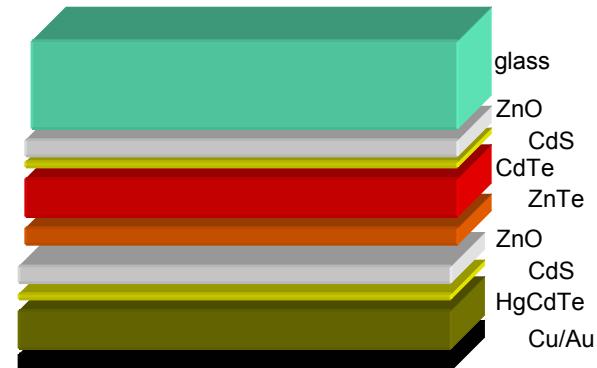


Transmission and reflectance after each step of tandem cell process



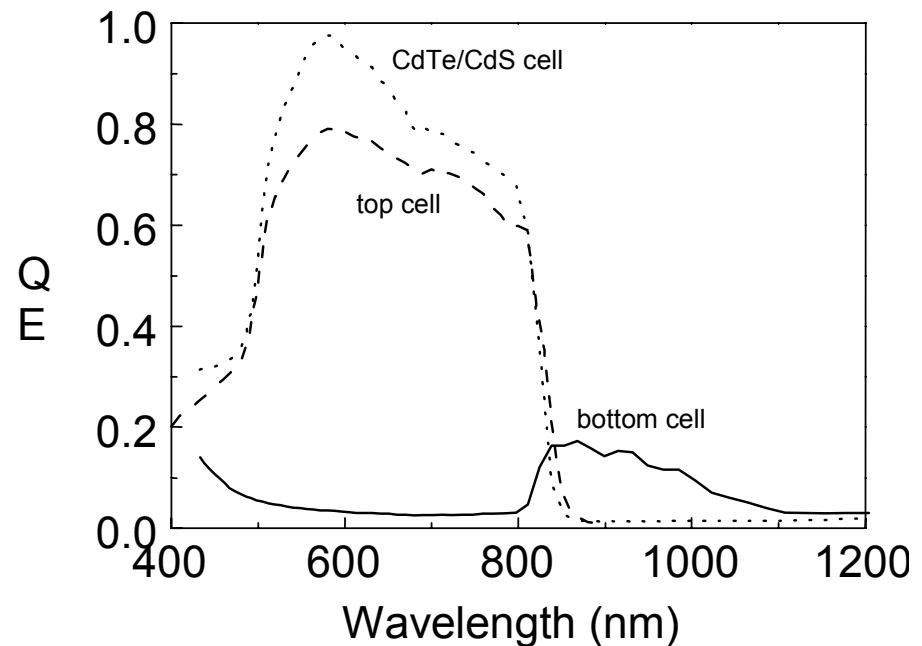
Structure:

- 1) Superstrate: Tec7
- 2) Top cell: CdS: 0.13 μm , CdTe 1.34 μm
- 3) Recombination junction: ZnTe(Cu):100 nm, ZnO(Al):100 nm
- 4) Bottom cell: CdS: 0.13 μm , HgCdTe ($E_g=1.1\text{eV}$): 1.56 μm



QE response shows independent junctions

- Top cell QE (flooding bottom cell with IR light) is close to single junction CdTe cell
- Bottom cell QE (flooding with 633 nm) is poor—partly due to limited light coupling from top but mostly due to poor carrier collection
- Recently carrier collection has been improved through the use of band gap grading: (CdS/CdTe/HgCdTe)



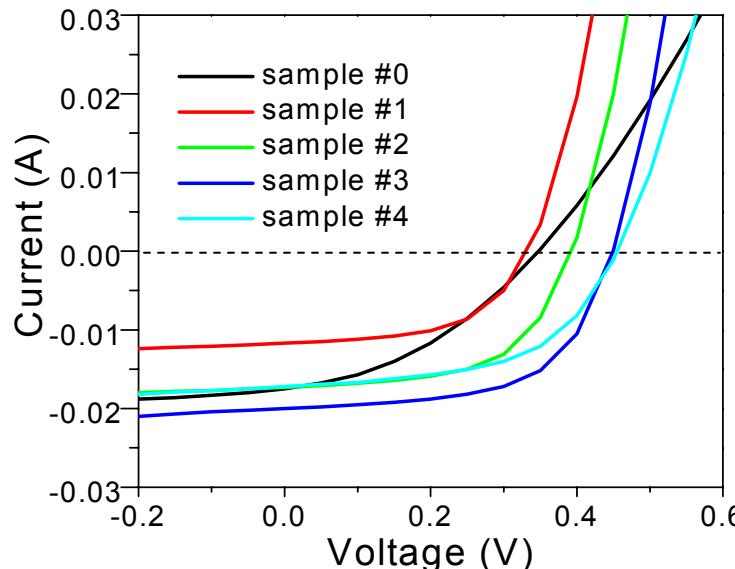
Improvements with CdTe junction buffer

HgCdTe/CdS single junction cell performance

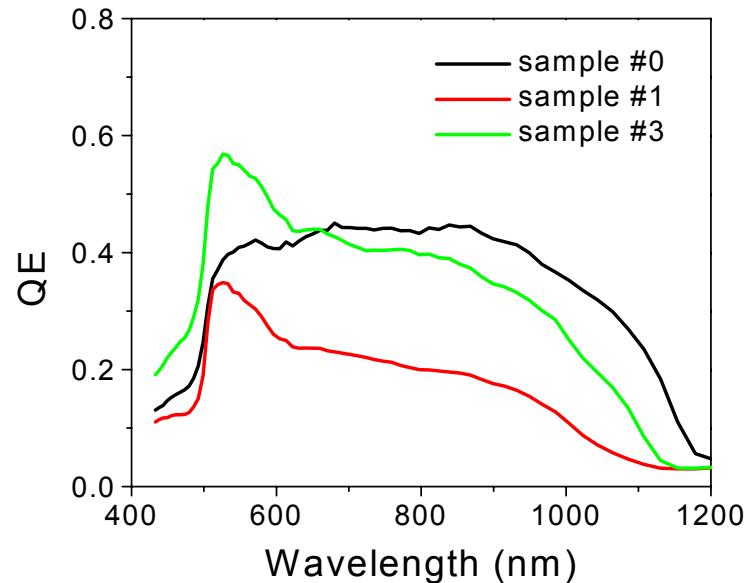
Sample	CdTe buffer (nm)	Voc (V)	Jsc (mA/cm ²)	FF (%)	Eff (%)
#0	0	0.35	17.8	38	2.3
#1	0	0.33	11.6	56	2.1
#2	30	0.39	17.3	58	3.9
#3	60	0.45	20.0	59	5.3
#4	80	0.45	17.2	54	4.2

#0 cold-pressed HgCdTe target (x=70%)
#1-4 sintered HgCdTe target (x=77%)

I-V curves for different CdTe buffer layers



QE for different buffers



Conclusions

- Magnetron sputtering of II-VI materials appears to be compatible with the fabrication of second junctions in tandem polycrystalline PV
- RTSE provides submonolayer, real time information on growth process of polycrystalline films
- A polycrystalline interconnect junction works (ZnTe:N/ZnO:Al)
- HgCdTe bottom cells show promise for superstrate structure tandems
- Wide-gap II-VI materials sputter easily but are difficult to activate with chloride treatments